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# Initial density dependence of viscosity of nonpolar-polar gaseous mixtures

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## INITIAL DENSITY DEPENDENCE OF VISCOSITY OF NONPOLAR-POLAR GASEOUS MIXTURES

BY MASARU HONGO

The initial density dependence of gas viscosity,  $\alpha' = \eta_0^{-1}(\partial\eta/\partial\rho)_{P \rightarrow 0}$ , of nonpolar-polar mixtures was determined from  $\alpha'$  of the pure components of the mixture, where  $\eta$  is gas viscosity,  $\rho$  density, and  $\eta_0$  the viscosity extrapolated to zero density. The calculated  $\alpha'$ -values expressed mostly those obtained from the experimental data for the hydrogen-ammonia system, the nitrogen-ammonia system, and the argon-ammonia system.

The gas viscosity  $\eta$  depends on pressure  $P$  or density  $\rho$  and can be expressed as follows:

$$\eta = \eta_0 (1 + \alpha P + \dots) \quad (1)$$

or

$$\eta = \eta_0 (1 + \alpha' \rho + \dots) \quad (2)$$

where  $\eta_0$  is the viscosity extrapolated to zero pressure (or density),  $\alpha = \eta_0^{-1}(\partial\eta/\partial P)_{P \rightarrow 0}$  the initial pressure dependence of viscosity, and  $\alpha' = \eta_0^{-1}(\partial\eta/\partial\rho)_{P \rightarrow 0}$  the initial density dependence of viscosity<sup>1)</sup>.

In the previous paper<sup>2)</sup>, a theoretical equation about  $\alpha$  derived by Stogryn and Hirschfelder<sup>3)</sup> was studied and  $\alpha'$  of a nonpolar and polar gas were semi-empirically introduced. The calculated  $\alpha'$ -values represented well the experimental ones obtained from viscosity data.

The object of this report is to determine  $\alpha'$  of nonpolar-polar gaseous mixtures from  $\alpha'$  of the pure components of the mixture. As the compressibility factor  $z$  is expressed in a power series expansion in density<sup>4)</sup>

$$z = PV/RT = 1 + B\rho + C\rho^2 + \dots \quad (3)$$

where  $V$ : volume;  $T$ : temperature;  $R$ : gas constant; and  $B$  and  $C$ : second and third virial coefficient, the coefficient of  $\rho$  in Eq. (2),  $\alpha'$ , corresponds to the second virial coefficient. As mentioned in the previous paper<sup>5)</sup>, it was seen that the correlation between  $\alpha'$  and the reduced temperature  $T_r$  was similar to that between the reduced second virial coefficient and the reduced temperature  $T^*$ . The following equation was introduced, consequently, to  $\alpha'$  of gaseous mixtures.

$$\alpha'_{mix} = \sum_{a=1}^2 \sum_{b=1}^2 \alpha'_{ab} x_a x_b \quad (4)$$

1) M. Hongo and H. Iwasaki, *This Journal*, **47**, 90 (1977)

2) M. Hongo, *ibid.*, **49**, 1 (1979)

3) D. E. Stogryn and J. O. Hirschfelder, *J. Chem. Phys.*, **31**, 1545 (1959)

4) J. O. Hirschfelder, C. F. Curtiss and R. B. Bird, "Molecular Theory of Gases and Liquids", John Wiley & Sons, Inc., New York (1954)

5) M. Hongo, *This Journal*, **48**, 63 (1978)

where  $x$  is mole fraction and  $a$  and  $b$  denote molecular species. Further, by considering the experimental results that the larger the molecular weight of nonpolar gases is, the stronger the effect on  $\alpha'$  of ammonia is, and that the higher the temperature is, the smaller the  $\alpha'$  is, the final expression was obtained as follows:

$$\left(\frac{M_{np}\alpha'}{b_o}\right)_{np} = x_n^2 \left(\frac{M_n\alpha'}{b_o}\right)_n + 2x_n(1-x_n) \left(\frac{M_n}{M_p}\right)^{1/2} (T_{np}^*)^{-1/2} + (1-x_n)^2 \left(\frac{M_p\alpha'}{b_o}\right)_p \quad (5)$$

where  $M_{np} = x_n M_n + (1-x_n) M_p$ ;  $b_o = 2\pi N\sigma^3/3$ ;  $T_{np}^* = T/\epsilon_{np} k^{-1}$ ;  $M$ : molecular weight; subscripts np denotes nonpolar-polar mixture and n and p denote nonpolar and polar gas.  $(M_n\alpha'/b_o)_n$  and  $(M_p\alpha'/b_o)_p$  are calculated from Eq. (11) for a nonpolar gas and from Eq. (12) for a polar gas in Ref. 2. The force constants of the Lennard-Jones potential and of the modified Stockmayer potential were used for a nonpolar and polar gas, respectively. The following combination rules were applied for nonpolar-polar interactions<sup>6)</sup>.

$$\sigma_{np} = (\sigma_n + \sigma_p)\xi^{-1/6}/2 \quad (6)$$

$$\epsilon_{np}/k = (\sqrt{\epsilon_n \epsilon_p}/k)\xi^2(\sqrt{z_{cn}} + \sqrt{z_{cp}})^{-2} \quad (7)$$

where  $\xi$  is defined in Eq. (8.6-5) in Ref. 4 and  $z_c$  is critical compressibility factor.

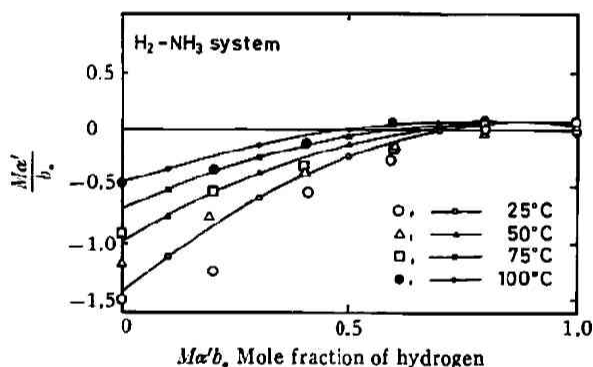


Fig. 1 Comparison of experimental value of  $M\alpha'/b_o$  with calculated one obtained from Eq. (8) for hydrogen-ammonia system

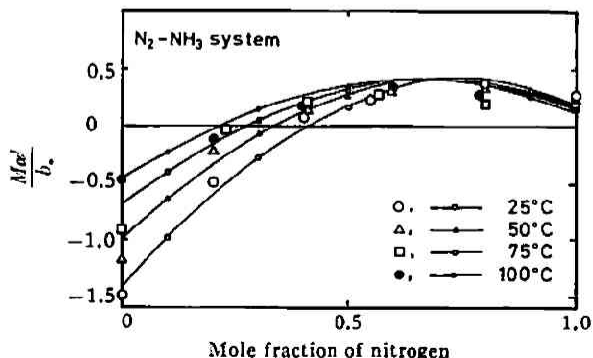


Fig. 2 Comparison of experimental value of  $M\alpha'/b_o$  with calculated one obtained from Eq. (8) for nitrogen-ammonia system

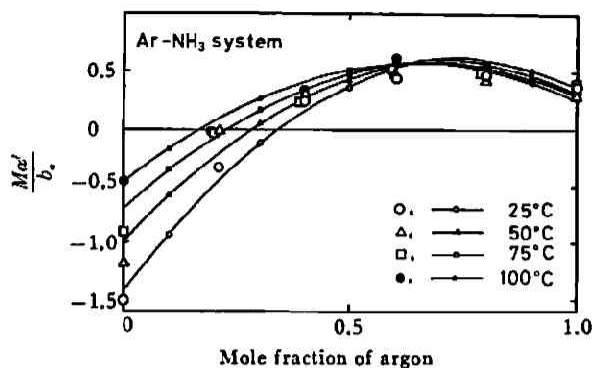


Fig. 3 Comparison of experimental value of  $M\alpha'/b_\infty$  with calculated one obtained from Eq. (8) for argon-ammonia system

Figures 1~3 show the calculated value of  $(M_{np}\alpha'/b_\infty)_{np}$  obtained from Eq. (5) (denoted by solid lines with small symbols), in comparison with the experimental one (denoted by large symbols) for the hydrogen-ammonia system<sup>6)</sup>, the nitrogen-ammonia system<sup>1)</sup>, and the argon-ammonia system<sup>5)</sup>. As shown in the figures, the results of the calculations represented well the experimental values except the ammonia-rich region of the hydrogen-ammonia system.

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6) M. Hongo and H. Iwasaki, *This Journal.*, **48**, 1 (1978)